

Psychophysiological Activation During Preparation, Performance, and Recovery in High- and Low-Anxious Music Students

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Abstract The present study provides a comprehensive view of (a) the time dynamics of the psychophysiological responding in performing music students ($n = 66$) before, during, and after a private and a public performance and (b) the moderating effect of music performance anxiety (MPA). Heart rate (HR), minute ventilation (V_E), and all affective and somatic self-report variables increased in the public session compared to the private session. Furthermore, the activation of all variables was stronger during the performances than before or after. Differences between phases were larger in the public than in the private session for HR, V_E , total breath duration, anxiety, and trembling. Furthermore, while higher MPA scores were associated with higher scores and with larger changes between sessions and phases for self-reports, this association was less coherent for physiological variables. Finally, self-reported intra-individual performance improvements or deteriorations were not associated with MPA. This study makes a novel contribution by showing how the presence of an audience influences low- and high-anxious musicians' psychophysiological responding before, during and after performing. Overall, the findings are more consistent with

models of anxiety that emphasize the importance of cognitive rather than physiological factors in MPA.

Keywords Psychophysiology · Musicians · Music performance anxiety (MPA) · Stage fright · Quality

Introduction

Research on the affective and physiological manifestations of performance stress in musicians has strongly focused on the phases shortly before and/or during a performance. Various studies have shown an increase in the affective and physiological arousal before and/or during a public performance compared to non-public performances (i.e., practice session, rehearsal) (e.g., Brotons 1994; LeBlanc et al. 1997; Yoshie et al. 2009). Also self-reported symptoms of physiological arousal such as palpitations, perspiration, dry mouth, trembling, and disturbances in breathing patterns have been reported to occur in musicians before public performances (Plaut 1988; Steptoe 1989, 2001; Studer et al. 2011a; Wesner et al. 1990; Wolfe 1989). Since the period after the music performance has received only limited attention, there is a lack of understanding of the affective and physiological manifestations of performance stress in a comprehensive time perspective including the phases before, during, and after a performance. In order to investigate stress reactions as a whole, it is important to assess both the reactivity of affective and physiological parameters, i.e., the changes from before to during a performance, and their recovery. Recovery can be defined as “a post stress rest period that provides information about the degree to which the reactivity in the physiological and psychological parameters being measured persists after the stressor has ended” (Linden et al. 1997, pp. 117–118).

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As in all performance contexts, performance anxiety in musicians—called music performance anxiety (MPA) or stage fright (but see Brodsky (1996) and Studer et al. (2011b) for a discussion of the nomenclature)—is a widespread phenomenon (Kenny et al. 2004). The first study testing low- and high-anxious musicians and assessing a physiological parameter (i.e., heart rate (HR)) before, during, and after a private (audience-free) performance and a public one was carried out by Fredrikson and Gunnarsson (1992). To our knowledge, there are no other comparable studies to date. Fredrikson and Gunnarsson (1992) reported that HR was higher in the public than in the private condition. Furthermore, HR was higher during than before or after the performances. Finally, the HR increase between before and during the performance was greater in the public session than in the private session. With respect to MPA, these authors found that high-anxious musicians had higher HR than low-anxious musicians during the public performance phase compared to the private performance phase. They did not report whether there were differences in the recovery phase depending on the anxiety level or the session.

It is not clear yet whether anxiety has a moderating effect on the psychophysiological responding during recovery. Based on findings on other anxiety disorders than MPA (i.e., panic disorder, generalized anxiety disorder), there is evidence that the impact of anxiety on the psychophysiological responding may be more obvious during the recovery phase than before or during a stressful situation (Roth et al. 1998; Wilhelm et al. 2001). However, Mauss et al. (2003) did not find any differences in the physiological recovery among high- and low trait socially anxious persons after a public speaking task.

In the field of music performance, HR is the most often assessed indicator of physiological arousal (Abel and Larkin 1990; Brotons 1994; Craske and Craig 1984; Fredrikson and Gunnarsson 1992; LeBlanc et al. 1997; Mulcahy et al. 1990; Yoshie et al. 2009; Yoshie et al. 2008). Other physiological indices such as skin conductance (Yoshie et al. 2009; Yoshie et al. 2008), blood pressure (Abel and Larkin 1990), hormone levels (Fredrikson and Gunnarsson 1992), and muscle tension (Yoshie et al. 2009; Yoshie et al. 2008) were assessed less often. Also respiration has been rarely investigated and the focus was exclusively on respiratory rate (Craske and Craig 1984). This is unfortunate given the evidence for the association between respiration and affect and anxiety (Abelson et al. 2010; Boiten et al. 1994) and more specifically between self-reported breathing-related symptoms and MPA (Studer et al. 2011a; Widmer et al. 1997). In a recent publication, we reported how affective experience, somatic symptoms, and cardiorespiratory behavior change *prior* to a private and a public performance as a function of

MPA (Studer et al. 2012). Self-reported affect and somatic symptoms, HR, and various respiratory parameters all increased before the public performance compared to before the private performance. Whereas the increases in the self-reports were higher in high- as compared to low-anxious musicians, MPA had no moderating effect on the physiological variables with the exception of the partial pressure of end-tidal CO₂ (PetCO₂). PetCO₂ increased from the private to the public session for musicians with low MPA levels and decreased for musicians with high MPA levels. In summary, respiration was stimulated before the public performance compared to the private performance. Respiration adjusted to the requirements of the music and the instrument is—especially for wind instrumentalists and singers—fundamental.

In this article, we report new data from the above-mentioned study (Studer et al. 2012) about the psychophysiological activation *during* and *after* the performances. Furthermore, contrary to the dichotomous anxiety classification used by Fredrikson and Gunnarsson (1992), we will assess MPA as a continuous variable. This will allow for a more complete analysis of the association of MPA with the affective and the (self-reported and actual) physiological activation before, during, and after a performance. Finally, we will address an issue that has received limited attention in past research, i.e., the quality of the performance and how it is affected by increased arousal and MPA. Findings on the influence of the performance setting (non stressful vs. stressful) and the anxiety level on the performance quality are somewhat inconsistent. While some researchers reported a decrease in the performance quality from the non stressful to the stressful performance situation (Yoshie et al. 2009), others reported no differences (Craske and Craig 1984) and still others reported even an increase in performance quality (Hamann and Sobaje 1983).

The main goal of this study was to provide a comprehensive view on the dynamics of self-reported variables (anxiety, tension, shortness of breath, difficulty breathing, palpitations, trembling, sweaty hands) and physiological variables (HR, V_E, total breath duration (T_{TOT}), and PetCO₂) before, during and after a private and a public music performance and to investigate the moderating effect of MPA. Based on previous research (Brotons 1994; Fredrikson and Gunnarsson 1992; Studer et al. 2012; Widmer et al. 1997; Yoshie et al. 2009), we hypothesized that musicians show stronger arousal with respect to the physiological variables (HR, V_E, T_{TOT}) and the self-report variables during a public performance compared to a private performance (hypothesis 1) and during the performance compared to before or after the performance (hypothesis 2). We also expected to find stronger physiological and self-reported arousal in musicians with higher

usual levels of MPA as compared to musicians with lower usual levels of MPA (hypothesis 3). Furthermore, we hypothesized that the changes in the physiological and self-reported arousal between phases are larger in the public session than in the private session (hypothesis 4), that musicians with higher usual levels of MPA as compared to musicians with lower usual levels of MPA show a larger increase in self-reported and physiological arousal between the private and the public session (hypothesis 5) and larger changes between phases in the public session as compared to the private session (hypothesis 6). We also hypothesized that the session-dependent changes between phases are larger with increasing MPA levels (hypothesis 7).

The secondary goal of this study was to examine how the quality of the performance is affected by MPA. Given the mixed evidence concerning the association between MPA and the quality of performance, we analyzed this issue in an exploratory way.

Methods

Data presented in this paper were collected during an experimental study published in Studer et al. (2012). This previous publication focused on the phase before a private and a public music performance to analyze in detail the anticipatory performance anxiety. The present paper extends this previous report by additionally analyzing the phases during and after the performances.

Participants

Seventy-four students from six Swiss music universities participated in this study. Eight musicians had to be excluded because they did not participate in all measurement sessions, because they were not compliant with the experimenter's instructions, or due to technical failure. Thus, the final sample was composed of 66 students (59 % female). Participants were 16–30 years old ($M = 23.2$; $SD = 3.4$) and their professional music education at the university level ranged between the first and eighth year. The sample composition was 18 % singers, 27 % wind instrumentalists, 30 % string players, 18 % pianists, and 7 % miscellaneous.

Procedure

All participants were tested individually in three sessions: baseline session, private session, and public session, separated by approximately 1 week each. The goal of the baseline session was to familiarize the participants with the measurement devices, the experimenter, and the study design as well as to assess the baseline values for the

dependent variables. The participants did not have to perform in the baseline session. For the private and the public session they performed the same “moderately difficult” musical pieces, which they were free to choose. The private session always preceded the public session to mirror as much as possible real performance situations, i.e., rehearsal before concert (cf. Studer et al. 2012). Both sessions encompassed a warm-up phase to tune the instrument or the voice, a pre-performance phase (in a preparation room), a performance phase (in an adjacent concert room), and a post-performance phase (again in the preparation room). Each phase lasted for approximately 10 min. The participants were sitting during each phase with the exception of singers, wind instrumentalists, violinists, and a double-bass player who were standing during the private and the public performance phase. During the pre- and the post-performance phases, the musicians were left alone and they were allowed to read. The private and the public session were identical with the following exceptions: In the public session, an audience composed by approximately ten persons was present. Furthermore, the public performance was audio recorded, and the musicians were told that two experts in the audience would evaluate the performance.

Measurements

Assessment of MPA

MPA can be considered as state anxiety with trait character. It is reasonable to assume that MPA remains stable for identical performance situations—at least over a certain time period. Therefore, we assessed the students' usual MPA level using the state scale of Spielberger's State Trait Anxiety Inventory (STAI-S) (Spielberger et al. 1970). The instructions were slightly adapted as done previously (Widmer et al. 1997) and asked how they had felt before recent public solo performances they considered important. The STAI-S consists of 20 items addressing apprehensive feelings of anxiety. Each item was rated on a 4-point Likert scale (1 “not at all” to 4 “very much so”). The score of this questionnaire can range from 20 (no anxiety) to 80 (extreme anxiety). The STAI-S was chosen for several reasons. First, almost all studies on MPA have used different ad hoc questionnaires; thus, there is no criterion standard questionnaire to assess MPA. By contrast, the STAI-S—although somewhat unspecific—has been widely used in research on (performance) anxiety (Brodsky 1996; Widmer et al. 1997). Second, the STAI-S allowed us to assess the affective dimension, which is the central component of the experience of MPA in many musicians (Stephoe 2001), as continuous variable. The score of the STAI-S is referred to as “MPA score” throughout the article.

Physiological Measures

From a total of 13 assessed cardiorespiratory variables, we have maintained four key variables, i.e., HR, V_E , T_{TOT} , and $PetCO_2$. HR was chosen as cardiac parameter, V_E as respiratory flow parameter, T_{TOT} as respiratory timing parameter, and $PetCO_2$ as indicator for hyperventilation (Van Diest et al. 2009). Additionally, data of the accelerometer (ACC) are reported to control for the physical activation. Physiological parameters were sampled continuously over all the assessment periods, except $PetCO_2$, which was not sampled during the performance phase, because the nasal assessment would have interfered with the singers' and wind instrumentalists' ability to perform and since other instrumentalists do not breathe exclusively through the nose while performing.

The electrocardiogram (ECG), the respiratory flow and time parameters, as well as the ACC data were assessed with the LifeShirt[®] system, a non invasive ambulatory assessment device (VivoMetrics Inc., Ventura, CA, USA; see Wilhelm et al. (2006) for a detailed description of the system). This snugly fitting T-shirt uses respiratory inductive plethysmography, which is the criterion standard for unobtrusive respiratory monitoring. Data were sampled at 200 Hz for the ECG and at 50 Hz for respiratory timing and volume parameters. $PetCO_2$ was recorded by means of a nasal canula connected to a non-dispersive infrared CO_2 monitor with a resolution of 1 mm Hg, an accuracy of 2 mm Hg, a sampling flow rate of 50 mL/min, and a sampling rate of 40 Hz (Microcap Hand-held Capnograph, Oridion Medical 1987Ltd., Jerusalem).

Self-report Measures

The affective experience was assessed with two single-items, i.e., “anxiety” and “tension”. The perceived physiological activation (i.e., somatic symptoms) was assessed with five single-items, i.e., “difficulty in breathing deeply”, “shortness of breath”, “palpitations”, “trembling”, and “sweaty hands”. Each item was rated on an 11-point Likert scale ranging from 1 “not at all” to 11 “extremely”. These self-reports were assessed (a) at the beginning and at the end of the pre-performance phase, (b) at the beginning of the post-performance phase to rate retrospectively the affective experience and the perceived physiological activation during the performance, and (c) at the end of the post-performance phase. Since the differences in the ratings between the beginning of the pre-performance phase and its end were not significant, they were considered as a repeated measure.

Self-rated Quality of the Performance and Effort

At the end of the post-performance phase in the private and the public condition, all musicians were asked to rate the quality of their performance on a scale from 1 “very bad”

to 11 “excellent” and the effort they put into the performance on a scale from 1 “none” to 11 “very much”.

Data Editing

The ECG and $PetCO_2$ data were analyzed using ANSLAB (Wilhelm and Peyk 2006). The respiratory flow and timing parameters were analyzed with VivoLogic, provided by VivoMetrics Inc. (Ventura, CA, USA). V_E was determined with an 800 ml fixed volume bag calibration. This calibration was carried out in the sitting and standing position and applied to the respective position of the musicians. For all physiological measures, data were averaged over the 10-min assessment period of each session. For a more detailed description of the data editing see Studer et al. (2012).

Statistical Methods

All analyses were performed using Stata version 11.0 for Windows (Stata Statistical Software, StataCorp LP, Texas). For the regression analyses of right-skewed continuous variables (V_E and T_{TOT}), the latter were logarithmically transformed in order to achieve approximate normality. For the statistical analyses, the physiological data were averaged over the 10-min pre-performance, performance, and post-performance periods, respectively. The physiological variables and the psychological variables were analyzed with generalized linear mixed models with a subject-specific random intercept. This statistical method allowed us to examine jointly the effect of the independent variables at the unchanging subject level (MPA score, instrument group, gender) and at the condition level [session, phase, and physical activation (ACC)] as well as the interactions between Phase \times Session, Session \times MPA, Phase \times MPA, and Phase \times Session \times MPA. Since the self-report variables were recorded on an ordinal scale and were, therefore, not amenable to the standard linear mixed model analysis, we used for them the ordered logistic mixed model analysis. This model is a direct generalization of the ordinary two-outcome logistic model. An underlying score is estimated as a linear function of the independent variables and a set of cut points. The parameters estimate of the model can be interpreted as a log-odds ratio assumed to be identical for all cut points (Rabe-Hesketh and Skrondal 2008).

The modelling strategy proceeded as follows: the first regression model (M1), used to test hypotheses 1–3, included all main effects of interest (session, phase, MPA score), additionally controlling for gender, instrument group, and ACC.¹ Subsequently, four interaction models were fitted

¹ Independent variables were coded as follows: session: private = 0 public = 1; phase: pre-performance = 0, performance = 1, post-performance = 2; MPA score = continuous; gender: women = 0, men = 1; instrument group: non wind instrumentalists = 0, wind instrumentalists = 1; ACC = continuous.

sequentially: The first interaction model (M2) used to test hypothesis 4 added the Phase \times Session interaction to M1. The second interaction model (M3) used to test hypothesis 5 added the Session \times MPA interaction to M2. The third interaction model (M4) used to test hypothesis 6 added the Phase \times MPA interaction to M3; and finally, the fourth interaction model (M5) used to test hypothesis 7 added the Phase \times Session \times MPA third-order interaction to M4. Regression analyses display the results always with respect to a reference group within each independent variable. Thus, in order to show the global effect of Phase, Phase \times Session, Phase \times MPA, and Phase \times Session \times MPA, we additionally performed post-estimation Wald tests (indicated by the χ^2 statistics in the text). The variable “phase” was further analyzed by pairwise post-estimation comparisons of each variable level (i.e., before, during, and after the performance) with multiplicity adjustment according to Sidak. This procedure allowed us to compare the various phases within and across sessions. To report the Phase \times Session interaction effect in an intelligible way, we additionally report the differences in change scores between phases over the sessions. Finally, to investigate the self-rated quality of the performance and its association with the performance condition (private vs. public) and the MPA score, the Pearson correlation coefficients were calculated.

Results

The descriptive results for each phase of the private and the public session are given in Table 1. Since musicians with

lower MPA scores and musicians with higher MPA scores did not differ from each other with respect to any of the self-report or physiological variables during the baseline session (Studer et al. 2012), this session is not taken into account any further. The results of the regression analyses for the physiological variables and the self-report variables are given in Table 2 and Table 3, respectively. The graphic representations of the physiological variables and a selection of the self-report variables are given in Fig. 1.

The analyses of “difficulty breathing”, “tension”, and “sweaty hands” yielded qualitatively comparable results. The same is true for “palpitations” and “shortness of breath”. In order to avoid repetitions, we present only one variable of these groups, i.e., “difficulty breathing” and “palpitations”.

Main Effects for Session, Phase, and MPA

HR, V_E and all self-report variables showed stronger activation during the public session as compared to the private session, thereby confirming hypothesis 1 on the session effect for these variables. Hypothesis 2 on the phase effect was confirmed for all physiological and self-report variables (HR: $\chi^2(2) = 370.75$; V_E : $\chi^2(2) = 775.37$; T_{TOT} : $\chi^2(2) = 44.75$; “anxiety”: $\chi^2(2) = 115.82$; “difficulty breathing”: $\chi^2(2) = 55.52$; “trembling”: $\chi^2(2) = 44.82$; “palpitations”: $\chi^2(2) = 89.15$; all $ps < 0.001$). HR, V_E , and all self-report variables were higher, respectively lower for T_{TOT} , during the performance than before and after. $PetCO_2$, which was not measured during performance, showed lower

Table 1 Means and standard deviations (in brackets) for all physiological variables and self-reports for the pre-performance, the performance, and the post-performance phases of the private and the public session

	Private session			Public session		
	Pre	Performance	Post	Pre	Performance	Post
Physiological variables						
HR (bpm)	76.3 (9.5)	98.1 (12.5)	74.5 (8.8)	84.0 (13.6)	126.2 (19.0)	82.9 (11.7)
V_E (l/min)	5.65 (2.21)	14.28 (6.93)	5.47 (2.15)	6.30 (2.62)	17.05 (8.48)	5.86 (2.50)
T_{TOT} (sec)	3.9 (0.8)	3.2 (1.3)	3.8 (0.7)	4.1 (1.0)	2.9 (1.2)	3.7 (0.7)
$PetCO_2$ (mmHg)	35.8 (2.7)		35.6 (2.6)	35.6 (2.9)		35.2 (2.7)
ACC	0.59 (.16)	1.73 (.76)	0.56 (.12)	0.65 (.16)	1.67 (.76)	0.62 (.16)
Self-report variables						
Anxiety	1.9 (1.3)	2.2 (1.7)	1.2 (0.5)	3.2 (2.1)	3.8 (2.6)	1.4 (0.8)
Tension	2.2 (1.5)	2.8 (1.8)	1.3 (0.6)	3.5 (2.1)	4.7 (2.6)	1.7 (1.0)
Shortness of breath	1.4 (0.6)	2.0 (1.5)	1.1 (0.3)	1.9 (1.3)	2.8 (2.3)	1.2 (0.6)
Difficulty breathing	1.5 (0.8)	2.1 (1.8)	1.2 (0.7)	2.1 (1.4)	3.5 (2.6)	1.4 (0.8)
Palpitations	1.4 (0.8)	2.4 (1.5)	1.1 (0.3)	2.5 (1.9)	4.2 (2.5)	1.4 (0.8)
Trembling	1.4 (0.9)	1.3 (1.0)	1.1 (0.3)	1.9 (1.6)	3.5 (2.6)	1.3 (0.7)
Sweaty hands	1.6 (1.3)	1.7 (1.5)	1.2 (0.6)	2.2 (1.9)	2.6 (2.2)	1.6 (1.0)

HR : heart rate; V_E : minute ventilation; T_{TOT} : total breath duration; $PetCO_2$: partial pressure of end-tidal CO_2 ; ACC: physical activation (accelerometer) with 0 “no movement” to 50 “fast running”. The self-report variables were rated from 1 “not at all” to 11 “extremely”

Table 2 Regression results (coefficients and 95 % confidence intervals) for the testing of the main and interaction effects of the session, phase, and MPA score (STAI-S) on the physiological variables, controlling for gender, instrument group (wind instrumentalists vs. non wind instrumentalists), and physical activation (ACC)

Model	HR		$V_E(\log)$		$T_{TOT}(\log)$		PetCO ₂	
	M1	M2	M1	M2	M1	M2	M1	M3
<i>Main effects</i>								
Session								
Public vs. private	14.76*** [12.87; 16.66]	7.74** [4.96; 10.52]	0.11*** [0.07; 0.15]	0.10** [0.04; 0.16]	-0.02 [-0.06; 0.02]	0.05 [-0.02; 0.13]	-0.18 [-0.45; 0.08]	1.20** [0.51; 1.89]
Phase								
During vs. before	32.65*** [29.09; 36.22]	21.61*** [17.91; 25.30]	0.93*** [0.86; 1.00]	0.89*** [0.81; 0.98]	-0.27*** [-0.35; -0.19]	-0.19*** [-0.29; -0.09]		
After vs. before	-1.50 [-3.82; 0.82]	-1.81 [4.59; 0.97]	-0.05* [-0.10; -0.01]	-0.03 [-0.09; 0.03]	-0.05+ [-0.10; 0.01]	-0.01 [-0.08; 0.06]	-0.31* [-0.57; -0.05]	-0.19 [-0.54; 0.15]
MPA (continuous) ^a	-1.89 [-4.18; 0.40]	-1.90 [-4.18; 0.38]	0.06 [-0.02; 0.13]	0.01 [-0.00; 0.01]	0.01 [-0.02; 0.04]	0.01 [-0.02; 0.04]	0.13 [-0.32; 0.57]	0.36 [-0.10; 0.82]
Gender								
Male vs. female	-3.94 [-8.97; 1.10]	-3.96 [-8.98; 1.06]	0.18* [0.01; 0.34]	0.18* [0.01; 0.34]	-0.01 [-0.08; 0.06]	-0.01 [-0.08; 0.06]	3.25*** [2.27; 4.23]	3.25*** [2.27; 4.23]
Instrument group								
Wind-instrumentalists vs. non-wind instrumentalists	-1.84 [-6.95; 3.26]	-1.78 [-6.87; 3.31]	0.01 [-0.15; 0.18]	0.01 [-0.15; 0.18]	0.21*** [0.14; 0.28]	0.21*** [0.14; 0.28]	0.80 [-0.20; 1.79]	0.78 [-0.21; 1.78]
Accelerometer (continuous)	-0.59 [-3.10; 1.92]	0.21 [-1.94; 2.36]	0.01 [-0.04; 0.06]	0.01 [-0.04; 0.06]	-0.04 [-0.09; 0.02]	-0.04 [-0.10; 0.01]	-0.25 [-1.45; 0.94]	-0.15 [-1.30; 1.00]
<i>Interaction effects</i>								
Phase × Session								
During vs. before × public vs. private		20.36*** [16.42; 24.29]		0.07 [-0.02; 0.16]		-0.15** [-0.25; -0.04]		
After vs. before × public vs. private		0.67 [-3.26; 4.60]		-0.04 [-0.13; 0.05]		-0.08 [-0.18; 0.03]		-0.24 [-0.73; 0.25]
Session × MPA								
Public × MPA vs. private × MPA				0.00 [-0.03; 0.04]				-0.48*** [-0.70; -0.26]
Phase × MPA								
During × MPA vs. before × MPA				-0.08*** [-0.12; -0.04]				
After × MPA vs. before × MPA				-0.01 [-0.05; 0.03]				

Table 2 continued

Model	HR		$V_E(\log)$		$T_{TOT}(\log)$		PetCO ₂	
	M1	M2	M1	M2	M1	M2	M1	M3
Constant ^b	80.62*** [72.39; 88.85]	83.65*** [75.46; 91.84]	1.43*** [1.17; 1.69]	1.43*** [1.17; 1.69]	1.28*** [1.16; 1.40]	1.25*** [1.13; 1.37]	33.90*** [32.20; 35.60]	33.17*** [31.46; 34.89]

The coefficients are in the unit of the variable, i.e., bpm, ml, sec, mmHg

M1–5 : Regression models 1–5

Interpretation aid: The predicted value for HR in the public session during the performance for a very low anxious (MPA score = 20), male wind-instrumentalist without any movement (ACC = 0) is: $83.65 + 7.74 + 21.61 - 1.90 \times 0 - 3.96 - 1.78 + 0.21 \times 0 + 20.36 = 127.62$

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.10$

^a by units of 10 points on the STAI-S scale

^b The constant refers to the private session before the performance for a non-anxious (MPA score = 20), female, and non-wind instrumentalist who shows no movement (ACC = 0)

values after the performance than before the performance. Whereas the MPA score had no significant effect on any of the assessed physiological variables, the self-report ratings significantly increased with increasing MPA scores. Thus, hypothesis 3 was confirmed for the self-report variables, with the exception of “palpitations” ($ps < 0.05$).

Interaction Effect: Phase \times Session

Hypothesis 4 on the Phase \times Session interaction was confirmed for HR ($\chi^2(2) = 132.6$, $p < 0.001$), V_E ($\chi^2(2) = 6.27$, $p < 0.05$), T_{TOT} ($\chi^2(2) = 7.43$, $p < 0.05$), “anxiety” ($\chi^2(2) = 10.45$, $p < 0.01$), and “trembling” ($\chi^2(2) = 19.33$, $p < 0.01$). The effect of the phase was thus not uniform across the sessions for these variables. Whereas HR was significantly higher in each phase of the public session as compared to the corresponding phase in the private session (before: +7.7 bpm, during: +28.1 bpm, after: +8.4 bpm; $ps < 0.001$), the biggest increase was observed between the two performance phases. Post-hoc analysis revealed that the interaction effect was due to both the larger increase from the pre-performance to the performance phase (private: +21.6 bpm; public: +42.0 bpm) and the larger decrease from the performance to the post-performance phase (private: −23.4 bpm; public: −43.1 bpm) in the public session compared to the private session ($p < 0.001$). Also V_E was higher before and during the public performance as compared to the corresponding phases in the private session (before: +11 %, during: +19 %; $p < 0.01$, $p < 0.001$, respectively). The post-performance phase was not significantly different between the two sessions. Post-hoc analysis revealed that the interaction effect was due to the stronger decrease from the performance to the post-performance phase in the public session (65 % decrease) compared to the private session (60 % decrease) ($p < 0.05$). T_{TOT} was significantly shorter during the public performance as compared to during the private performance ($p < 0.05$). T_{TOT} showed a larger decrease from the pre-performance phase to the performance in the public session compared to the private session (−29 % vs. −17 %; $p < 0.05$).

Also the self-report variables were significantly higher before, during, and after the public performance as compared to the corresponding phase in the private performance (all $ps < 0.05$ with the exception of “anxiety” after the performance). Although the differences in the self-ratings after the performance between the private and the public session were significant, they were of small magnitude. Post-hoc analyses for the two self-report variables with a significant Phase \times Session effect showed that the decrease for “anxiety” from before to after the performance and from during to after the performance ($ps < 0.01$) was stronger in the public than in the private session. For “trembling”, the

Table 3 Regression results (coefficients and 95 % confidence intervals) for the testing of the main and interaction effects of the session, phase, and MPA score (STAI-S) on the self-report variables (affective experience, somatic symptoms), controlling for gender, instrument group (wind instrumentalists vs. non wind instrumentalists), and physical activation (ACC)

Model	Anxious				Difficulty breathing				Trembling				Palpitations			
	M1	M2	M3	M4	M1	M3	M4		M1	M2	M3	M4	M1	M2	M3	M4
<i>Main effects</i>																
<i>Session</i>																
Public vs. private	2.03*** [1.62; 2.45]	2.27*** [1.74; 2.80]	-0.32 [-1.42; 0.79]	-0.35 [-1.44; 0.74]	1.63*** [1.22; 2.05]	0.00 [-1.09; 1.09]			2.39*** [1.86; 2.91]	1.63*** [0.99; 2.27]			2.22*** [1.77; 2.66]			1.30* [0.22; 2.38]
<i>Phase</i>																
During vs. before	0.82* [0.15; 1.50]	0.76 ⁺ [-0.08; 1.60]	0.82 ⁺ [-0.02; 1.66]	-0.89 [-2.24; 0.46]	1.25** [0.54; 1.96]	0.99* [0.10; 1.87]			1.55*** [0.74; 2.37]	-0.19 [-1.36; 0.99]			2.04*** [1.34; 2.75]			0.67 [-0.57; 1.92]
After vs. before	-3.28*** [-3.90; -2.66]	-2.25*** [-3.09; -1.41]	-2.16*** [-2.98; -1.34]	-3.18** [-5.09; -1.28]	-1.78*** [-2.35; -1.22]	-1.72*** [-2.61; -0.82]			-1.80*** [-2.49; -1.11]	-2.07** [-3.31; -0.83]			-2.30*** [-2.91; -1.69]			-2.21* [-3.98; -0.45]
MPA (continuous) ^a	0.93*** [0.62; 1.25]	0.92*** [0.60; 1.25]	0.47* [0.10; 0.83]	0.28 [-0.10; 0.65]	0.40* [0.05; 0.76]	0.14 [-0.25; 0.53]			0.92*** [0.55; 1.29]	0.63*** [0.23; 1.04]			0.07 [-0.26; 0.40]			-0.38 ⁺ [-0.83; 0.06]
<i>Gender</i>																
Male vs. female	-0.06 [-0.83; 0.70]	-0.03 [-0.86; 0.81]	-0.15 [-1.20; 0.90]	-0.36 [-1.25; 0.53]	-0.01 [-0.73; 0.71]	-0.01 [-0.73; 0.72]			-0.58 [-1.41; 0.24]	0.11 [-0.88; 1.10]			0.08 [-0.59; 0.76]			0.12 [-0.53; 0.76]
<i>Instrument group</i>																
Wind-instrumentalists vs. non-wind instrumentalists	-0.44 [-1.19; 0.30]	-0.47 [-1.28; 0.35]	-0.53 [-1.58; 0.53]	-0.71 [-1.60; 0.18]	-0.04 [-0.74; 0.66]	0.02 [-0.71; 0.75]			-0.77 [-1.78; 0.24]	-1.19* [-2.09; -0.28]			-0.75* [-1.42; -0.08]			-0.76* [-1.40; -0.13]
Accelerometer (continuous)	-0.14 [-0.62; 0.35]	-0.10 [-0.58; 0.38]	-0.15 [-0.64; 0.34]	-0.23 [-0.72; 0.26]	0.16 [-0.37; 0.69]	0.12 [-0.42; 0.66]			-0.22 [-0.80; 0.37]	-0.06 [-0.69; 0.57]			0.16 [-0.33; 0.65]			0.04 [-0.44; 0.52]
<i>Interaction effects</i>																
<i>Phase × Session</i>																
During vs. before × public vs. private		0.06 [-0.77; 0.90]	0.18 [-0.66; 1.01]	0.16 [-0.68; 1.00]		0.61 [-0.27; 1.48]				2.51*** [1.39; 3.64]						0.10 [-0.75; 0.95]
After vs. before × public vs. private		-1.75** [-2.85; -0.64]	-2.10*** [-3.22; -0.98]	-2.18*** [-3.32; -1.04]		-0.11 [-1.23; 1.00]				0.41 [-1.04; 1.86]						-0.87 [-2.08; 0.34]
<i>Session × MPA</i>																
Public × MPA vs. private × MPA			0.95*** [0.59; 1.32]	0.99*** [0.62; 1.35]		0.54** [0.19; 0.90]										0.40* [0.05; 0.75]
<i>Phase × MPA</i>																
During × MPA vs. before × MPA				0.66** [0.26; 1.07]												0.58** [0.20; 0.96]
After × MPA vs. before × MPA				0.35 [-0.22; 0.92]												0.18 [-0.34; 0.70]

The coefficients are log odds ratios

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ⁺ $p < 0.10$ ^a by units of 10 points on the STAI-S scale

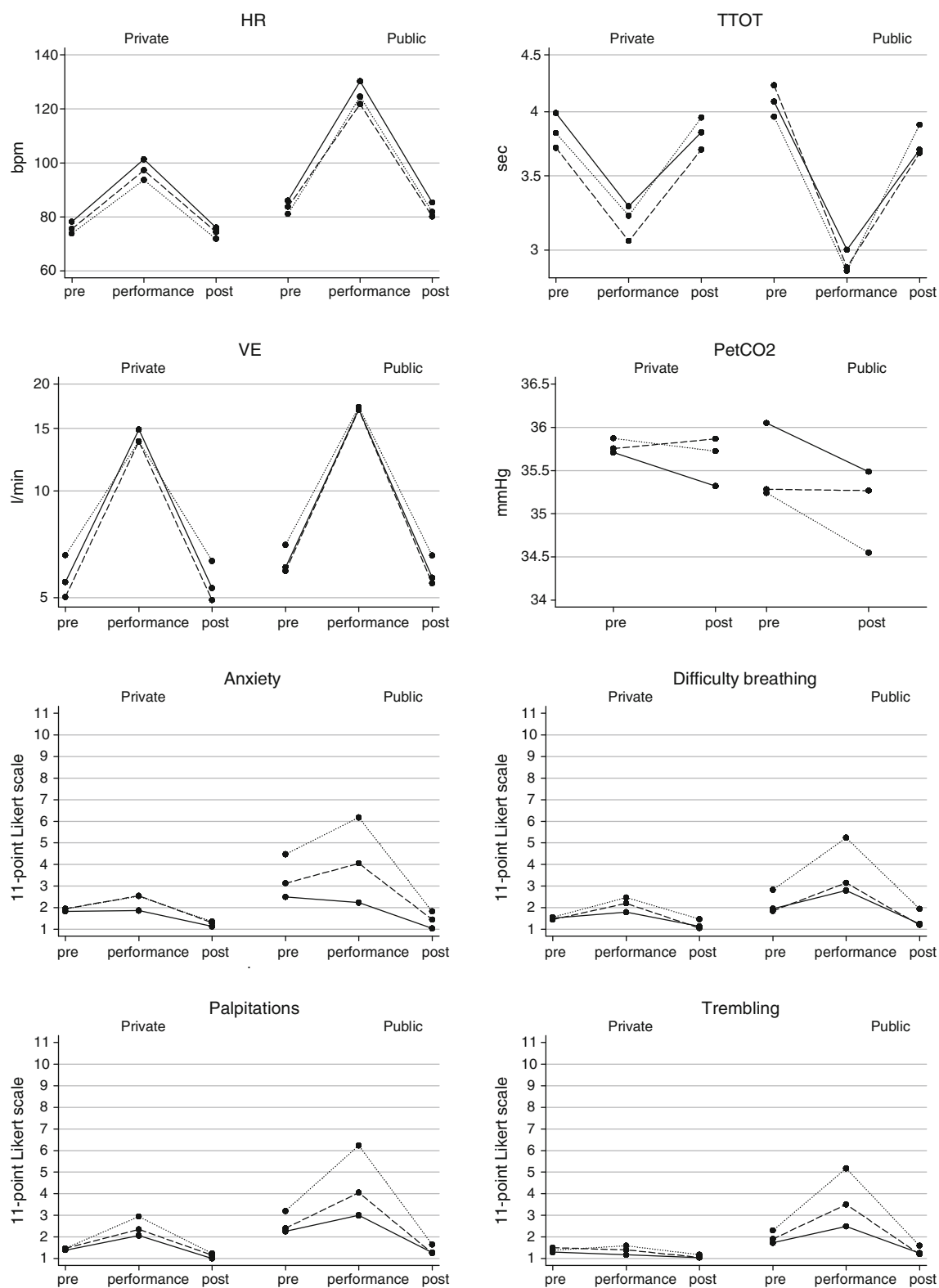


Fig. 1 Observed values for physiological and self-report variables over the different assessment periods. To depict the effect of the MPA score on the dependent variables, the figure presents the mean values for the least anxious musicians (STAI-S: 20–44; *solid line*), the

moderately anxious musicians (STAI-S: 45–54; *dashed line*), and the most anxious musicians (STAI-S: 55–80; *dotted line*). Y-axes for T_{TOT} and V_E are log scales

increase from before to during the performance and the decrease from during to after the performance were stronger in the public than in the private session ($ps < 0.05$).

Interaction Effects: Session \times MPA and Phase \times MPA

Hypothesis 5 on the Session \times MPA interaction was confirmed for PetCO₂, “anxiety”, and “difficulty breathing”. The PetCO₂ of the least anxious musicians increased from the private to the public session, whereas the PetCO₂ of the most anxious musicians decreased. This effect is illustrated in Fig. 1 and described in detail in Studer et al. (2012) for the pre-performance phase. Also for the self-report variables, the main effect of the session was amplified by increasing MPA scores, with the exception of “trembling” and “palpitations”.

There was a significant Phase \times MPA effect for V_E ($\chi^2(2) = 16.59$, $p < 0.001$), “anxiety” ($\chi^2(2) = 10.48$, $p < 0.01$) and “palpitations” ($\chi^2(2) = 8.92$, $p < 0.05$). Hypothesis 6 was, thus, confirmed for these variables. Whereas V_E was significantly higher with increasing MPA before the performance ($p < 0.05$) and marginally higher after the performance ($p = 0.07$), MPA showed no effect on V_E during performance. Thus, the Phase \times MPA effect was manifest in (a) a less steep increase from the pre-performance to the performance phase with increasing MPA scores ($p < 0.001$) and (b) a less steep decrease from the performance to the post-performance phase with increasing MPA scores ($p < 0.01$).

Finally, there was no significant Phase \times Session \times MPA interaction for any physiological or self-report variable. Hypothesis 7 was, therefore, completely rejected.

Self-rated Quality of the Performance and Effort

The musicians made an effort to play at their best in both sessions [private: $M = 8.2$ ($SD = 2.0$); public: $M = 9.2$ ($SD = 1.5$)]. Overall, the self-ratings of the private and the public performance quality were not significantly different (private session: $M = 6.1$ ($SD = 1.8$) vs. public session: $M = 6.2$ ($SD = 2.1$), $t(63) = -0.40$, $p = 0.69$, two-sided). Twenty-eight musicians rated their public performance as being better than their private performance, whereas 18 rated their private performance as being better than their public performance. Eighteen musicians rated their performance identically in both the private and the public condition. The performance rating was only weakly, though significantly, correlated with the MPA score in both the private session ($r = -0.26$; $p < 0.05$) and the public session ($r = -0.33$; $p < 0.01$). The correlation between MPA and the change score of the self-rating of the performance, i.e., the difference between the private and the

public performance, was even weaker and not significant anymore ($r = -0.10$; $p = 0.41$).

Discussion

The main goal of the present study was to investigate the physiological activation and the self-reported affective experience and somatic symptoms during performance stress in musicians in a comprehensive time perspective. To this end, we analyzed the phases before, during, and after a private and a public performance. Furthermore, we investigated the moderating effect of MPA on the physiological activation and the self-reported variables. Finally, we also investigated the association between the musicians' self-rating of the performance quality and their MPA score.

HR and V_E showed a stronger activation during the public session than during the private one. Furthermore, their activation and the one of T_{TOT} were stronger during the performances than before or after. These results are in line with previous research (Brotons 1994; Fredrikson and Gunnarsson 1992; LeBlanc et al. 1997; Mulcahy et al. 1990; Spahn et al. 2010; Yoshie et al. 2009). Previous studies reported that the HR of musicians was 99–112 bpm during a low-stress performance (practice, rehearsal) (Brotons 1994; LeBlanc et al. 1997; Yoshie et al. 2009). This level of activation during musical performance is in between HR at rest in healthy adults (70 bpm) and HR during moderate to heavy exercise (150–180 bpm) (McArdle et al. 2006). Thus, part of the increased physiological activation we observed during the public performance can be explained by the physical demands of musical performance. The physical effort due to performing, however, does not explain why the activation for HR and V_E was stronger during the public performance than during the private one (+28.1 bpm for HR and +2.77 l/min for V_E). Furthermore, given the fact that neither the Session \times MPA interaction nor the Phase \times Session \times MPA interaction were significant, also MPA cannot explain the higher physiological activation during the public performance. Also globally, there was no association between the physiological variables and the MPA score. The same lack of association between physiological activation and anxiety was previously reported for HR, skin conductance level, and respiratory sinus arrhythmia in high trait socially anxious individuals versus low trait socially anxious individuals in a public speaking task (Mauss et al. 2003).

Compared to during the private performance, HR and V_E were significantly higher during the public performance and T_{TOT} was significantly smaller. Although being significant, the observed changes in T_{TOT} during the public

performance were of rather small magnitude contrary to the changes in HR and V_E . This may be due to the fact that T_{TOT} is bound more tightly to the demands of a musical piece than other physiological variables. This applies particularly to wind instrumentalists and singers. For these instrument types breathing is strongly determined by the music. Nevertheless, T_{TOT} was slightly shorter in the public performance phase than in the private one. In a previous study on pianists, Yoshie et al. (2009) reported a tendency to play faster in a public competition condition than in a rehearsal condition without audience. For wind instrumentalists and singers, faster playing goes along with an increase in the respiratory rate. This link between increased tempo and decreased T_{TOT} might also apply—although to a lesser degree—to the other instrument groups. Previous studies have shown that the mere listening to music induced significant increases in breathing rate with faster musical tempi. This result was even more obvious in musicians than in non-musicians (Bernardi et al. 2006). Furthermore, Ebert et al. (2002) reported an association between meter rate, tempo, and breathing rate. Thus, future studies would benefit from taking into account the association between breathing rate and tempo.

PetCO₂ values after the performance were significantly lower than before, although only slightly (see Fig. 1). This might be due to a tendency to breathe in excess of metabolic requirements (i.e., hyperventilate) during the performances. To confirm this hypothesis, future studies should assess PetCO₂ during the performance. Furthermore, there was a difference in PetCO₂ values between the private and the public session depending on the MPA level of the musician. More precisely, PetCO₂ increased from the private to the public session for low-anxious musicians whereas it decreased for high-anxious musicians. Again, the decrease from the stress-free to the distressing performance situation may be due to an underlying hyperventilation problem in high-anxious musicians. This phenomenon is discussed in detail for the phase before the performance in Studer et al. (2012).

The MPA level also affected the changes between phases in V_E . In high-anxious musicians compared to low-anxious musicians V_E increased less strongly between the pre-performance phase and the performance phase and decreased less strongly between the performance and the post-performance phase. This was due to the fact that high-anxious musicians had higher V_E than low-anxious musicians before and after the performance but were comparable during the performances. One could assume that V_E is by default higher in more anxious musicians than in less anxious musicians. However, given that V_E was comparable in higher and lower anxious musicians during the baseline (data not shown) and during performance, this conclusion does not hold. The investigation of worry and

post-event rumination and their influence on respiration might elucidate this finding in future studies (Kenny 2011).

In line with the findings of Ballegaard et al. (2009) and Fredrikson and Gunnarsson (1992), our results show the expected pattern of psychophysiological responding before, during, and after acute stress, i.e., activation from before to during the performance phase and recovery from during to after the performance phase (see also McEwen and Seeman 2003). However, despite significant decreases in the physiological activation from the public performance phase to the post-performance phase, HR did not decrease to the post-performance level of the stress-free private session. Nevertheless, the recovery was in absolute terms stronger in the public session than in the private one. In future studies, it would be interesting to investigate how long it takes for the musicians after a public performance to reach the post-performance level of a stress-free performance.

As for HR and V_E , the ratings for all self-report variables were (a) higher in the public session than in the private session and (b) higher during the performance as compared to before and after it. Thus, they also showed the expected pattern of activation and recovery from before to during and from during to after acute stress. The finding of increased self-reported measures during the performances is somewhat contradictory to Salmon's assertion that anxious apprehensions are strongest before rather than during a public performance (Salmon 1990). However, it is not clear which time period Salmon termed "before performance". "Before performance" might refer to the period *immediately* prior to the performance when the musicians walk on stage and are confronted with the audience rather than to the period 10 min before the performance. Furthermore, all self-report variables were consistently associated with the MPA score (i.e., the STAI-S score), showing that higher anxious musicians reported globally higher ratings for the affective experience and for the self-perceived somatic symptoms. Contrary to the physiological variables, MPA amplified the session effect in all self-report variables with the exception of "trembling". The main effect of the phase was amplified only for some self-report variables ("anxiety" and "palpitations").

Clearly, whereas there was a consistent association between MPA and self-report variables, the association between MPA and the physiological variables was much less consistent. This finding is in line with previous studies showing that musicians with a high level of affective performance anxiety do not globally differ from low-anxious musicians at the physiological level (Craske and Craig 1984; Fredrikson and Gunnarsson 1992). The absence of physiological differences between high- and low-anxious subjects was also reported for other forms of anxiety (Anderson and Hope 2009; Grossman et al. 2001; Mauss

et al. 2003; Mauss et al. 2004). This is consistent with models of social anxiety which emphasize the importance of cognitive factors (such as attentional focus and dysfunctional appraisal) in the experience of anxiety (Clark and McManus 2002; Leary and Kowalski 1995). Thus, low-anxious musicians may focus their attention on the music pieces and their performance, whereas high anxious musicians focus their attention at least partly on bodily manifestations—especially during the performance phase when the self-reported symptoms are highest. In conclusion, the observed changes in the physiological activation are primarily attributable to the performance stress rather than to trait MPA. Spahn et al. (2010, p. 81) concluded in this respect that “physiological arousal may be a necessary condition for MPA, but it is not a sufficient explanation”.

When interpreting the above discussed results the likelihood of Type I errors should be kept in mind given the large number of statistical tests that were carried out. However, the response pattern for the main effects of all variables and for the Session \times MPA interaction effects of the self-report variables is coherent and repeated. Also for those effects with low to very low p values Type I errors are unlikely.

Finally, the musicians rated their performance as being worse with increasing levels of usual MPA in the private and the public sessions. However, the correlation between the self-rated quality of the performance and the MPA score was only weak. Furthermore, there was no evidence that intra-individual performance improvements or deteriorations from the private to the public session were associated with the MPA score. Quality ratings by the musician him-/herself yield valuable information given that the musician knows best which level of performance s/he is capable to achieve. Also, musicians’ opinion on their own performance is highly important for their personal satisfaction. However, personal ratings might be influenced by individual expectations and character traits such as perfectionism. Therefore, further studies might want to compare experts’ ratings with musicians’ ratings. In this case, attention should be paid to the fact that expert ratings are prone to be biased depending on whether the rater sees or only hears the performer (Fredrikson and Gunnarsson 1992).

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